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ScienceDirect
Energy Procedia 88 (2016) 297 – 304
Energy Procedia

CUE2015-Applied Energy Symposium and Summit 2015: Low carbon cities and urban energy systems

Research On The Us Electricity Market Based On Price Fluctuations

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Abstract

Electricity power is the basic industry and it plays an important role in the national economy. Based on the random matrix theory (RMT), we study the average correlations evolution of electricity price among 51 states, and identify their four regime shifts during the period of January 1990 to August 2014 in the U.S. residential, commercial and industrial electricity markets. Then, the genetic algorithm is applied to the analysis of clusters evolution. The results show that, the correlations of electricity price increased continually in the three departments. However, it decreased in 2012 which verifying the sensitivity to fuel market further. Besides, four regime shifts exist in the three departments even though the different time of occurrence caused by price level. Finally, the research results are analysed and summarized.

Keywords: U.S. electricity market, Electricity price, Regime Shifts, Cluster evolution ;

1. Introduction

Electricity industry[1-4] is the foundation of the national economy, and electricity price affects operating cost in other industries and the living standard of residents directly. In the 1980s, the reform of electricity industry has swept the world[5,6]. Western countries began to loosen the regulations, restructured and established a competitive electricity market, which have promoted the progress of the global electricity market. In the U.S., most of the electricity industries belong to privatization. Electricity industry reform mainly means reducing regulation as well as increasing competition. The programs of reform were different by regions. But, the only purpose is to fuse market mechanism into the electricity industry, to optimize and improve the allocation and efficiency of resources using competition and privatization.

In recent years, as one of the most important commodities for national development and people's life, electricity market is concerned by researchers and policy makers increasingly. It should be mentioned that

doi:10.1016/j.egypro.2016.06.146

related surveys on electricity market have been previously conducted by a few researchers and organizations. Peter Cappers et al. [7] summarize the existing contribution of Demand Response resources in U.S. electricity markets. They concluded that competition is critical to the development of electricity markets. A more recent update was accomplished by G. Castagneto-Gissey [8] in 2014 on European electricity market. They analyzed the interactions of a representative sample of 13 European electricity spot prices during the period 2007-2012 based on complex network theory. Their model is able to create a time-varying network describing the evolving influences among the European electricity prices, is able to detect important changes in market integration and can be considered a suitable and promising approach for this task.

The existing literatures has provided a solid empirical investigation and a good reference to understand the evolution of a certain electricity market around the world, but some research of U.S. electricity market still need to be further implement. The U.S. electricity market is one of the largest electricity markets in the world, and it is also the first country to reform. There are two reasons for us to study the U.S. electricity market. One is for its more mature operation mechanism and supervision systems. Another is the higher market competition. The main objectives of our survey efforts are to explore the principle of the U.S. electricity market from the angle of electricity price, and to provide a reference for research in future electricity market. It is also our hope that this research could be used to facilitate reform scheme for China electricity market, as well as to help energy investors assess the overall potential risk of electricity market.

Nomenclature

RMT	Random Matrix Theory
M	Month
S	Size of moving window

2. Data and Methods

2.1. Data

In this paper, the data of electricity prices are divided into three kinds: residential, commercial and industrial both for 51 states and the U.S. Each kind of data is recorded monthly from 1990M1 to 2014M8, given a total of 296 values (http://www.eia.gov/).

2.2. Methods

(1) Moving windows and Correlation coefficient matrix. P_i (t) presents the t-month electricity price of i-state (i=1, 2, 3…51). Then, the logarithmic return at time t is defined as

$$r_i(t) = \ln P_i(t) - \ln P_i(t-1) \tag{1}$$

For each window, we compute the correlation matrix C(t), whose element C_{ij} is the Pearson correlation coefficient[9] between the return time series of states i and j.

$$C_{ij} = \frac{1}{\sigma_i \sigma_j} \sum_{t-s+1}^{t} \left[r_i(k) - u_i \right]\left[r_j(k) - u_j \right] \tag{2}$$

To estimate the empirical correlation matrix and minimize the statistical uncertainty, we use $s = 60$ which has a total of 236 windows.

(2) Random matrix theory. If M is a $T \times N$ matrix with mean 0 and variance $\sigma^2 = 1$, we define $C = \frac{1}{T} M^T M$. In the limit $N \to \infty, T \to \infty$ where $Q = T / N \geq 1$ is fixed, the probability density $f_{RMT}(\lambda)$ of eigenvalues λ of matrix C is $f_{RMT}(\lambda) = \frac{Q}{2\pi}\sqrt{(\lambda_{\max} - \lambda)(\lambda - \lambda_{\min}) / \lambda}$, where $\lambda \in [\lambda_{\min}, \lambda_{\max}]$ and $\lambda_{\min,\max} = 1 + 1/Q \pm 2\sqrt{1/Q}$. If an eigenvalue λ is greater than $\lambda_{\max}$ and thus deviates from the prediction of the RMT[10,11], its eigenvector frequently contains valuable information about market dynamics.

(3) Least-squares regression. For each eigenvalue λ_n its Eigen portfolio [12] is constructed. Then, the returns $R_n(t')$ is calculated by

$$R_n(t') = U_n^T(t') \bullet r(t') \tag{3}$$

Where $t' = t - s + 1, \ldots, t$, and $r(t') = \left[r_1(t'), \ldots, r_{51}(t') \right]^T$. To evaluate the collective market information embedded in λ_n, we investigate the following linear regressive model between $R_n(t')$ and the return $R(t')$ of the U.S. electricity price

$$R_n(t') = k_n(t) R(t') + \varepsilon(t') \tag{4}$$

Where R is defined in Eq.(1) by the data of overall price index of three departments in the U.S..

(4) Genetic algorithm. To evaluate the quality of the partitions, we introduced the algorithm developed by Girvan and Newman [13]. The modularity [14] measures the density of links inside communities compared to links between communities, and can be used to evaluate the quality of the partitions obtained by a method. The modularity is defined as

$$M = \sum (e_{ii} - a_i^2) = tr(e) - \left\| e^2 \right\| \tag{5}$$

Where e_{ij} means the fraction of all edges in the network that link nodes in community i to nodes in community j. $tr(e) = \sum_i e_{ii}$ gives the fraction of all edges in the network that connect nodes in the same community. $a_i = \sum_j e_{ij}$ denotes the fraction of edges that connect to nodes in community i.

3. Empirical analysis of the U.S. electricity market

In this part, the average correlation coefficients, regime shifts and the clusters evolution are analysed in detail.

3.1. Correlation coefficient

The evolution of average correlation coefficients among 51 states is presented in Fig.1, which is calculated by Eq. (2).

It is considered widely for cost plus method to regulate electricity price in spite of the different pricing mechanisms in the U.S.. In addition, most of them adopt stepwise pricing. If the quantity of electricity that consumers used exceeds a certain limit, the unit price of electricity will be increased. However, the electricity prices of states are different due to the policy and cost of generation plants.

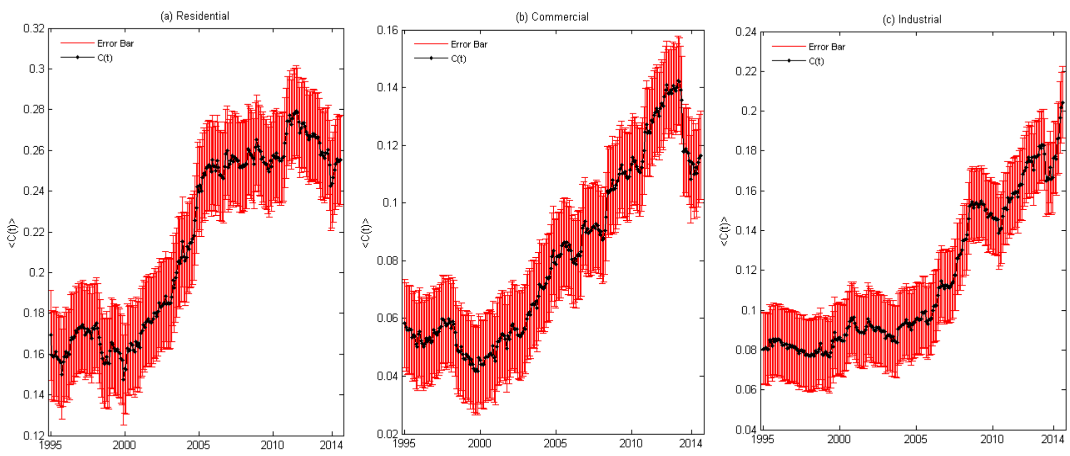

Fig. 1 Evolution of average correlation coefficients for electricity prices. Note: The error bar is the standard deviation of the PDF at each time t.

As showed in Fig. 1, the average correlation coefficients display sharply increasing in recent years. Thus, it indicates that the electricity price of 51 states (including residential, commercial and industrial) become strongly correlated with time going on due to the proportion adjustment between gas-electric and coal-electric. Lesser capital, shorter construction period and taken fully advantage of capacity are the advantages of gas-electric. Moreover, the coal-electric cost is associated with the transportation costs which dependent on the distribution of coal resources. As a result of the adjustment, the correlation of electricity price becomes high. Facing the changes, the correlation of the states' electricity prices is obvious, although their pricing mechanism is independent. However, the average correlation coefficients of the three departments have declined obviously in 2012. It means that the electricity price of 51 states become less correlated because of the recovering of coal-electric. Therefore, uneven distribution of coal resources lead to the various generating cost for states directly which has dropped the correlation coefficients, which verifying its sensitivity to fuel market further (as shown in Fig.2; Data downloaded from EIA Database: http://www.eia.gov/).

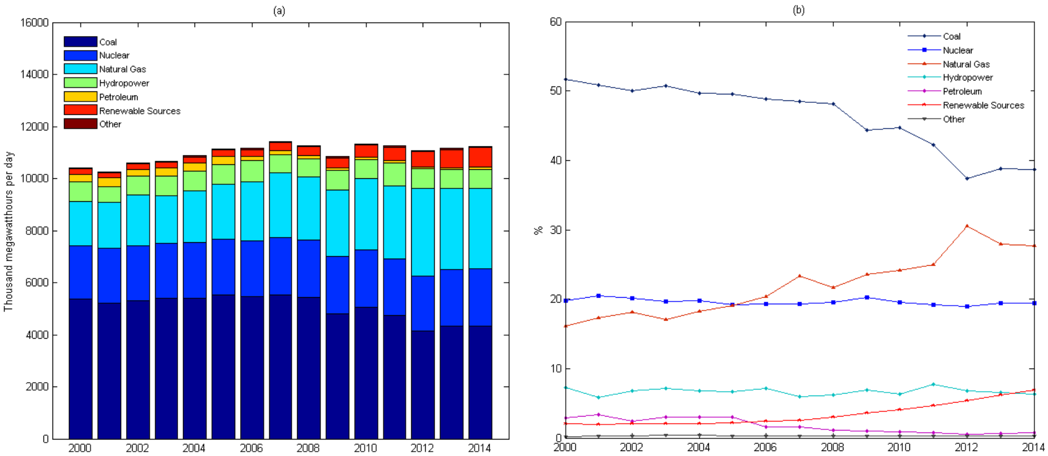

Fig. 2 Variation of electricity production, consumption and fuel prices in the U.S. Note: (a) Electricity production by energy in the U.S. (b) Variation of electricity production percentage by energy in the U.S.

3.2. Regime shifts

The first two largest eigenvalues are selected to research the nontrivial spatiotemporal properties of the U.S. electricity market dynamics based on RMT. Ultimately, four regime shifts are identified according to the methods of qualitative and quantitative. Fig.3 shows the evolution of the correlation coefficient $k_n(t)$ between R_n and R in each moving window based on Least-squares linear regression. $k_n(t)$ reflects the electricity market commonness between 51 states if $k_n(t)$ is high, if not, it means that electricity market being diversification.

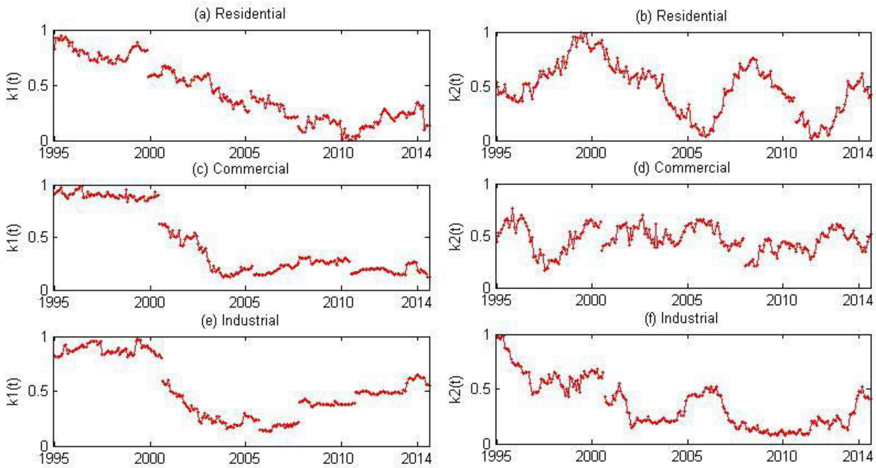

Fig. 3 Evolution of the regression coefficient $k_n(t)$ between R_n and R in each moving window.

Fig.3 (a) shows that the regression coefficient is larger for the first five years, and broken suddenly: from 0.8236 (1999M11) to 0.5695 (1999M12), from 0.2518 (2005M3) to 0.4605 (2005M4), and from 0.2029 (2007M9) to 0.1405 (2007M10). It indicates that there are three regime shifts corresponding to four periods: [1990M1, 1999M11], [1999M12, 2005M3], [2005M4, 2007M9] and [2007M10, 2014M8]. Fig.3 (b) indicates two periods: [1990M1, 2010M8] and [2010M9, 2014M8]. Therefore, five periods are identified: R1=[1990M1,1999M11], R2=[1999M12, 2005M3], R3=[2005M4,2007M9], R4=[2007M10,2010M8], R5=[2010 M9,2014M8].

Fig.3 (c)-(d) and Fig.3 (e)-(f) are the regressive results of the commercial and industrial departments, respectively. Similarly, five periods of commercial are R1=[1990M1,2000M6], R2=[2000M7,2005M5], R3=[2005 M6, 2007M12], R4=[2008M1, 2010M6] and R5=[2010M7, 2014M8]. Five periods of industrial are R1=[1990M1, 2000M8], R2=[2000M9,2005M9], R3=[2005M10, 2007M10], R4=[2007M11,2010M9] and R5=[2010M10,2014M8].

The cross-validation of the four regime shifts in the six plots of Fig. 3 indicates that our identification of five periods is valid. We concluded that the time of shift regimes occurred in three departments are inconsistent. The time that happened in residential is the earliest, while, the commercial and industrial are later which is affected by the level of price.

In period R1, coal-electric accounts for more than 50% of the electric capacity and its proportion is hardly fluctuations which has been the main source of electricity industry. Thus, the main influencing factor of electricity price is limited to coal cost and resource distribution, due to the oneness of electricity generation.

In period R2, the electricity market commonness was destroyed and the sources of electricity industry become diversification. And the percentage of gas-electric units gradually increased, On the contrary, the scale of coal-electric units declined dramatically. Coal-electric and gas-electric have become the main sources in electricity industry. It is consistent with Fig. 2. In 2005, the proportion of gas-electric units reached steady after the adjustment of R2. So in period R3, the U.S. electricity market kept this status until 2007.

In period R4, the outbreak of subprime crisis and the financial crisis have greatly influenced the international order which caused credit crunch effect in financial markets. The recession of financial caused great negative impact on fuel market, including coal and natural gas industry. Simultaneously, it also spread to the electricity industry. The electricity market emerge fluctuation due to the influence of the financial crisis on energy sources.

Period R5 is mainly influenced by the shale gas. Under the pressure of environment and energy, the exploitation of shale gas becomes popular by energy investors. The gas production reached a historic peak in 2011 and the cost of gas-electric generation is completely below the coal-electric. This transformation has a great impact on the electricity market of the U.S.

3.3. Evolvement of clusters

To confirm the five periods and better understand the spatiotemporal dynamics of the U.S. electricity market at the state level, we partition the states into clusters for each time t. We analysis the cluster and the corresponding modularity of 51 state prices according to genetic algorithm. Fig.4 shows the evolution of states clusters and modularity of the three departments.

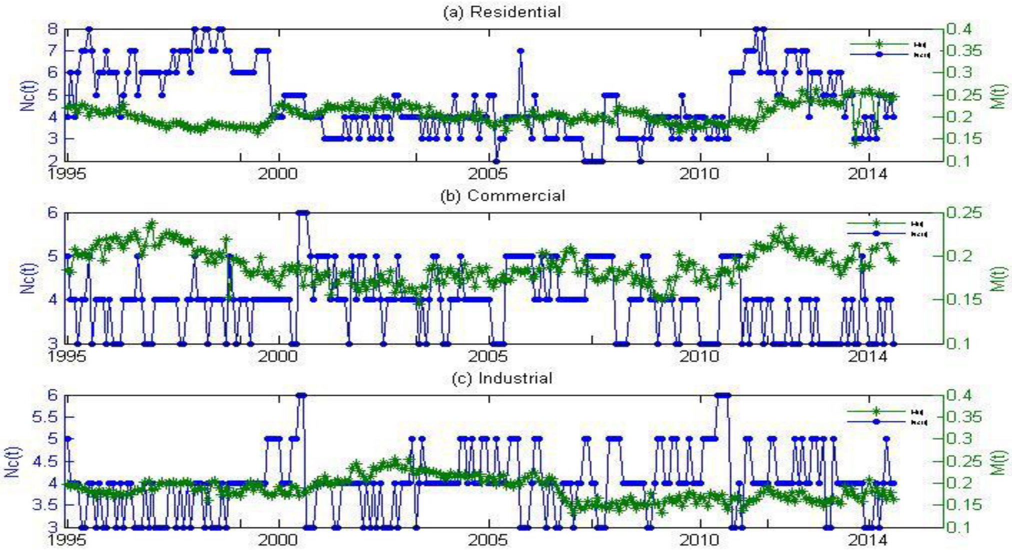

Fig. 4 Evolution of states clusters in residential, commercial and industrial markets. Note: The blue symbols number of clusters Nc(t), while the green ones are evolution of modularity M(t).

Modularity is one of the standards which measure the quality of community division. The values of M(t) are approximate to 0.2, and they fluctuate within the range ±0.05. This suggests that 51 states have a strong community structure and the clusters are reasonable. From Fig. 4, the points of sudden change are consistent with the four regime shifts of the three departments which discussed above. For the residential electricity market, the clusters are unstable with a large number of states shifting between clusters in Fig.4 (a). Meanwhile, Fig.4 (b) and (c) imply that the fluctuation of community evolution are relatively stable in the industrial and commercial departments. And the clusters in three departments are relevant to diverse electricity prices. In this part, we draw an important conclusion that the price level influences the evolution of community.

4. Conclusions

This paper studied the average correlations evolution of electricity price among 51 states in the U.S. residential, commercial and industrial electricity markets. The uncertainty influence from fuel market is analyzed emphatically based on eigenvalue and eigenvector of RMT. Simultaneously, four regime shifts with five periods are identified in the three departments by the methods of qualitative and quantitative. Through the empirical study above, some sound conclusions are drowning as follows.

First, the average correlation coefficients have increased continuously in the three electricity markets which reflect the commonness of electricity market. And this phenomenon is affected by the adjustment of the proportion for gas-electric and coal-electric directly. However, the average correlation coefficients decreased in 2012 due to the coal-electric recovering, which verifying the sensitivity to fuel market deeper.

Second, four regime shifts exist in the three departments even though the different time of occurrence. The regime shifts in commercial and industrial markets have the obviously hysteresis compare with residential which has the highest price level. The electricity price of residential is very sensitive and the turning point of residential is the earliest. Similarly, the reaction of low electricity price is obtuse. It demonstrated that the occurrence of regime shifts is in direct proportion to price level. The research on clusters evolution of 51 states in the three departments also verified the result further.

Acknowledgements

This research was supported by National Nature Science Foundation of China (No. 71273119 and No. 71473108) and the Graduate Innovative Foundation of Jiangsu Province KYLX15_1076.

References

[1] Kaile Zhou, ShanlinYang et al. Energy conservation and emission reduction of China's electric power industry. *Renewable and Sustainable Energy Reviews* 2015; 45:10-9.

[2] G. Castagneto-Gissey, M. Chavez. Dynamic Granger-causal networks of electricity spot prices: *A novel approach to market integration. Energy Economics* 2014; 44:422-32.

[3] Walawalkar R, Blumsack S, Apt J, Fernands S. An economic welfare analysis of demand response in the PJM electricity market. *Energy Policy* 2008; 36(10): 3692-702.

[4] Cappers P, Goldman C, Kathan D. Demand response in US electricity markets: empirical evidence. *Energy* 2010; 35(4):1526-35.

[5] Joskow,P.L.. Markets for Power in the US: an interim assessment. *J The energy Joumal* 2006; 27(1):1-36.

[6] Fereidoon P. Sioshansi, Wolfgang Pfaffenberger. Why Restructure Electricity Markets. *Electricity Market Reform*. 2006, 35-48.

[7] Peter Cappers, Charles Goldman et al, Demand response in U.S. electricity markets: Empirical evidence. *Energy* 35 (2010) 1526-1535.

[8] G. Castagneto-Gissey, M. Chavez, F. De Vico Fallani. Dynamic Granger-causal networks of electricity spot prices: A novel approach to market integration. *Energy Economics* 2014; 44:422-432.

[9] Song, D.-M., Tumminello, M., Zhou, W.-X. & Mantegna, R. Evolution of worldwide stock markets, correlation structure, and correlation based graphs. *Phys. Rev. E* 2011; 84: 026-108.

[10] Hao Meng. Wen-Jie Xie.etl. Systemic risk and spatiotemporal dynamics of the US housing market. *Scientific Reports*, 2014. 4 : 3655, DOI: 10.1038/srep03655.

[11] Hua Han, Linyan Wu, Ningning Song. Financial Network model based on random matrix. *Physics* 2014; 63(13), 138901.

[12] Plerou, V. Random matrix approach to cross correlations in financial data. *Phys. Rev. E* 2002; 65:066-126.

[13] Girvan, M., Newman, M., Community structure in social and biological networks. *Proc. Natl. Acad. Sci. USA* 2002; 99:7821-7826.

[14] Karsten Steinhaeuser, Nitesh V. Chawla. Identifying and evaluating community structure in complex networks. *Pattern Recognition Letters* 2010; 31:413-421.

Biography

Mei Sun is a Professor in Jiangsu University. She has been engaged in the theory and application of energy-economic system, chaos control and complex network, and published more than 50 academic articles in journals, which are indexed by SCI, by EI, or by ISTP. Her doctoral dissertation was rated as Top Dissertation of Jiangsu Province.